COMPARISON OF STATIC FRICTIONAL CHARACTERISTICS OF MOLYBDENUM DISULFIDE COATED AND UNCOATED TMA AND STAINLESS STEEL RECTANGULAR ARCHWIRES IN THE DRY STATE - AN IN VITRO STUDY

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CERTIFICATE

This is to certify that this dissertation titled "COMPARISON OF STATIC FRICTIONAL CHARACTERISTICS OF MOLYBDENUM DISULFIDE COATED AND UNCOATED TMA AND STAINLESS STEEL RECTANGULAR ARCHWIRES IN THE DRY STATE - AN IN VITRO STUDY" is a bonafide record of work done by **Dr. Rinosh Thomas** under my guidance during his postgraduate study period between 2010–2013.

This dissertation is submitted to THE TAMIL NADU Dr. M.G.R. MEDICAL UNIVERSITY, in partial fulfillment for the degree of **Master of Dental Surgery** in Branch V –Orthodontics and Dentofacial Orthopedics.

It has not been submitted (partially or fully) for the award of any other degree or diploma.

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List of Abbreviations

Abbreviation	Expansion
USS	Uncoated Stainless Steel
UTMA	Uncoated Titanium Molybdenum Alloy
CSS	Coated Stainless Steel
CTMA	Coated Titanium Molybdenum Alloy
MoS_2	Molybdenum Disulfide
NiTi	Nickel- Titanium

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Abstract

Introduction : During sliding mechanics, frictional resistance is an important counterforce to orthodontic tooth movement, which must be controlled to allow application of light, continuous forces .The present study involved the coating of rectangular TMA and Stainless steel (SS) archwires with Molybdenum Disulfide (MoS_2) which is an extensively used metal dichalcogenide solid lubricant .This has been done with the objective of reducing the static frictional properties of the archwires during sliding mechanics. The analysis was intended to compare the static frictional properties of molybdenum disulfide coated stainless steel and TMA archwires and uncoated stainless steel and TMA archwires with stainless steel brackets

Methods: All frictional tests were carried out in a dry state on an Instron 3345 testing_machine. The protocol advocated by Thomas et al[60] was followed.

Results: The measurements of peak load values were done for uncoated stainless steel, coated stainless steel, uncoated TMA and coated TMA archwires. The lowest static frictional value was recorded for the coated stainless steel archwire, followed by the uncoated stainless steel archwire. The static frictional forces of coated TMA archwires were higher than for uncoated stainless steel archwire, but with no statistically significant difference between the two. Uncoated TMA wires recorded the highest value of static frictional force.

Conclusion: Molybdenum Disulfide coated TMA archwires, coupled with stainless brackets seem to be a good alternative to stainless steel archwires during space closure using sliding mechanics.

Keywords: Static Friction, Molybdenum Disulfide, Sliding mechanics, Solid Lubricant.

Introduction

Orthodontic tooth movement is greatly influenced by the characteristics of applied force. Friction in clinical Orthodontics is now receiving much attention because the efficiency of tooth movement associated with orthodontic sliding mechanics can be compromised by friction between arch wire and tube or bracket slot. In clinical terms, the force applied must overcome this frictional component and achieve the desired tooth movement. The employment of such sliding mechanics bears many advantages such as less complicated wire bending, decreased chair side time and enhanced patient comfort[1].

However, this relative motion bears a disadvantage in that it results in the generation of frictional forces at the bracket – archwire interface, which tends to impede the desired tooth movement.[2]

Friction is defined as the resistance to motion when one object moves tangentially to another. The friction encountered during tooth movement can be categorized as **static** frictional force which is the smallest frictional force required to start the motion; and **kinetic** frictional force which is the force required to resist the sliding motion of one solid object over another at a constant speed[4].

The magnitude of friction depends on the amount of normal force pushing the two surfaces together, surface roughness and nature of materials from which the surfaces are made.[4]

For all practical purposes, kinetic friction is irrelevant in orthodontic tooth movement because continuous tooth movement rarely if ever occurs. When a force is applied, in order that an object move against the other, the applied force must overcome the frictional force. Higher frictional force requires the application of a greater orthodontic force.[5]

The loss of applied force has been commented on by many Chung et al[1] and Stoner [2] because it places an additional strain on the anchorage demands and leads to a resultant reduction in the rate of tooth movement.[1]

Low forces are desirable in orthodontics to conserve anchorage. They keep reciprocal forces low and facilitate release of binding forces between brackets and archwires thereby enhancing sliding mechanics.[6] Around 12-60 % [45] of applied forces in fixed appliance therapy is lost to friction.[8] Light forces can result in a less painful treatment experience for the patient and also help to maintain the position of anchorage teeth.[9,10,11]

Braun et al [9], Nikolai et al [18], Kusy et al[6] have used experimental testing models to evaluate the factors that influence frictional resistance between the brackets and the archwire.

These studies have shown that the important factors which determine the frictional levels were bracket[12], bracket slot[13,14], torque at the wire-bracket interface[15], wire materials[16] , surface conditions of archwires[17], wire section[18,19], type and force of ligation[20], interbracket distance[21], saliva and influence of oral functions[22]. Consequently, to achieve desirable results, the orthodontist would need to apply more force to overcome friction. The clinical advantage of reduced resistance to sliding will be reduction in the amount of time to align the teeth and close the spaces.

In the light of these statements, it is imperative, that as clinicians, we attempt measures to reduce the frictional force generated at the bracket-archwire interface. Fact remains that a stainless steel bracket and archwire combination remains to date the clinical favorite owing to the relatively low frictional forces generated.[6]

Archwires such as NiTi (Nickel-Titanium)[23], TMA (Titanium Molybdenum Alloy) which are now being widely used, are acknowledged for their high resiliency, low rigidity and shape memory. These properties have been employed effectively in clinical orthodontics.[23, 24-28]

TMA wires have an excellent combination of strength and flexibility. It is the wire of choice as an intermediate wire between initial alignment and finishing stages of treatment[26]. TMA archwires also have the desirable property that they produce linear forces per unit of deactivation and have substantially more range and higher springback[25]. Therefore it could be aptly stated that TMA is in fact the perfect wire, however with a latent flaw that the coefficient of friction was the worst of all alloys [5]. Clinically this relates to a slower rate of tooth movement observed during space consolidation and retraction occurred slower than stainless steel or cobalt-chromium.

Authors have suggested a variety of methods to overcome the frictional disadvantage of archwires. This includes various coatings applied on wires such as by ion implantation, applying a diamond like coating[8], nitrides etc. These coatings have however met with limited clinical success[8].

Therefore in the present study, a coating of rectangular **TMA** and **Stainless steel** (**SS**) wires with **Molybdenum disulphide (MoS_2)** was done**.** MoS_2 is an extensively used metal dichalcogenide solid lubricant, which finds application in fasteners and equipment for the space technology program. The coating was done with the objective of reducing the static frictional properties. Owing to the lubricating property of MoS_2, it is likely to have a potential for orthodontic applications.

The present study was done to evaluate and compare the static frictional properties of molybdenum disulfide coated stainless steel and TMA archwires and uncoated stainless steel and TMA archwires with stainless steel brackets.

Aims & Objectives

Aims & Objectives

The **aim** of the present study was to evaluate and compare the static frictional properties of molybdenum disulfide coated stainless steel and TMA archwires and uncoated stainless steel and TMA archwires with stainless steel brackets.

Review Of Literature

Friction had been mentioned in the orthodontic literature as far back as **1960** when **Stoner** [2] stated “Recognition must always be given the fact, sometimes applied force is dissipated by friction and it is difficult to control and determine the amount of force that is being received by the individual tooth”.

Frank CA et al (1980)[18] To produce tooth movement, the force generated from an orthodontic appliance must first overcome static frictional forces. To continue this movement, orthodontic forces must be greater than the kinetic frictional forces produced from the movement itself as well as the resistance caused by the periodontium.

Burstone et al (1980)[24] The beta-titanium wires are titanium molybdenum alloys, introduced for orthodontic use in 1979 by Burstone & Goldberg.

Burstone et al (1980)[25] Beta titanium was almost the perfect wire since its characteristics were so balanced; yet it had a latent flaw. The coefficient of friction was the worst of any orthodontic alloy and demonstrated higher levels of bracket/wire friction than either stainless steel or cobalt chromium wires

Burstone and Goldberg reported that the modulus of elasticity (E) of TMA is approximately twice that of nitinol and less than half that of SS. Its stiffness makes it ideal in applications where less force than steel is required but the lower modulus would be inadequate to develop required force magnitudes.

Frank et al (1980)[18] concluded that with edgewise bracket; friction might be minimized by maximizing the contact area of the wire within the bracket slot, maximizing the bending stiffness and minimizing the bracket width. He suggested a heavy rectangular wire with a narrow slot should be used for canine retraction in edgewise mechanics.

According to **Thurow et al (1982)**[29] allowing more clearance between the archwires and bracket slots by reducing the size of the wire relative to the slot of the bracket led to more tendencies towards bracket binding, which would increase the frictional resistance

JL Garner et al (1986)[30] These investigators envisioned TMA as an alloy for orthodontic use after recognizing its advantages as (1) elastic modulus below stainless steel and near to nickel-titanium (NiTi) conventional alloy, (2) excellent formability, (3) weldability (4) low potential for hypersensitivity. However, use of beta-Ti wire has disadvantages such as (1) high surface roughness, which increases friction at the wire-bracket interface during the wire sliding process, and (2) susceptibility to fracture during bending. To reduce surface roughness, a nitrogen ion implantation technique has been used. However, some authors have questioned the effectiveness of this process in the reduction of friction. Initially, beta titanium wires were used for specific application. Arch wire composition is among the variables that have an impact on the frictional forces produced in tooth movement .Various compositions may create greater frictional forces during tooth movement. As a result, they have an effect on the proficiency of tooth movement. Hence, it is important to understand which arch wire composition may increase or decrease the rate of tooth movement. Of equal importance is the investigation of processes that may help improve arch wire material.

Kusy RP et al (1987)[31] Use of beta-Ti wire has disadvantages such as (1) high surface roughness, which increases friction at the wire-bracket interface during the wire sliding process, and (2) susceptibility to fracture during bending.

Jastrezbski et al (1987)[32] has reported that all surfaces are more or less irregular , and the physical explanation of friction is in terms of the true area of contact, which is determined by asperities, and the force with which the surfaces are forced together.

Baker et al (1987)[10] determined the magnitude of frictional force changes between several sizes of stainless steel orthodontic wires and an edgewise bracket. They created wet conditions by introducing artificial saliva. It was concluded that archwire dimensions more closely approximating that of the bracket slot decreased the potential for binding forms of friction.

Kusy RP et al (1988)[33] Surface topography can critically affect esthetics and performance of orthodontic components.

Tidy (1989)[79] investigated frictional resistance to movement along a continuous arch wire. It was found that friction was proportional to applied load and inversely proportional to bracket width i.e. friction was greatest for narrow brackets. Arch wire dimension and slot size had little effect on friction. Nitinol and beta-titanium arch wire produced frictional forces two and five times greater than those of stainless steel

Berger et al (1990)[74] reported that the mode of ligation has a significant effect on the amount of friction generated during sliding mechanics.

RP Kusy et al (1991)[34] The composition of the wire alloy has a significant influence on friction. Beta titanium archwires generated more friction than stainless steel and nickel titanium archwires for all bracket- archwire combinations

Prososki et al (1991)[35] showed using a surface profileometer that low surface roughness was not a sufficient condition for low-friction coefficients. However, in these studies, surface roughness of the bracket slots was not considered.

Kusy et al(1991)[36] stated that in the dry state there was lower friction for SS. The friction in the dry state with beta titanium wires was greater than that of SS. This could be because the titanium-rich layer breaks down, reacts, adheres, and breaks away, resulting in a stick-slip phenomenon. When saliva was introduced, friction for titanium-based wires decreased to the levels of SS.

Sims,Waters and Birnie(1993)[37] stated that once leveling and alignment is complete and retraction begins, frictional forces increase significantly due to an increase in the archwire size, change from round to a rectangular cross-section wire, torque present in rectangular wires, and also as a result of surface morphology of the wire.

Dickson et al (1994)[38] Investigated static planar frictional resistance between five initial alignment wires and stainless steel brackets at three bracket to wire angulations (0, 5 and 10 degrees). They demonstrated that static frictional resistance increased significantly with increasing bracket to wire angulation due to binding within the system. They reported that epoxy-coated steel had the highest static frictional resistance and coaxial stainless steel the lowest. Fibre-optic glass (Optiflex) had low frictional resistance.

Downing et al (1995)[40] reported contradictorily on the effect of lubrication in frictional evaluation during sliding mechanics. The effect of artificial saliva on the static and kinetic frictional forces of stainless steel and polycrystalline ceramic brackets in combination with 0.018-inch round and 0.019 x 0.025-inch Edgewise archwire sizes and stainless steel, nickel-titanium and beta-titanium archwire materials, under a constant ligature force were investigated. In all cases, artificial saliva had the effect of increasing the frictional force when compared with the dry state.

Burstone and Farzin-Nia (1995)[41] showed that ion implantation increases archwire hardness, reduces flexibility, and improves surface finish. However, to achieve the best possible reduction in frictional force when using ion implanted materials, both the bracket and the archwire should be treated (ion implantation) repeatedly.

Burstone et al (1995)[41] It is described that the nitrogen ion implantation technique affords an extremely hard surface layer that would improve fatigue resistance and ductility and reduce the coefficient of friction in vitro. However, an in-vivo study reported that the rate of orthodontic space closure was not significantly different for ion implanted and non-ion-implanted TMA wires and that the rate of space closure was similar to that reported for stainless steel.

Hamula et al (1996)[76] evaluated the properties of titanium brackets and compared them with that of stainless steel brackets and they reported about 30% reduction in friction in titanium brackets when compared to stainless steel brackets. They reported that the formation of thin layer of titanium oxide prevented direct contact between the metallic atoms on the surfaces of the wire and bracket hence reducing inter atomic adhesion and friction and this being the reason for the reduced friction in titanium brackets

Kusy and Whitley(1999)[42] has categorized friction into 3 components (a) Friction ,static or kinetic due to contact of the wire with bracket surfaces (b) Binding which occurs when the tooth tips or the wire flexes , which results in a contact between the wire and the bracket corners. c) Notching which occurs when there is a permanent deformation of the wire at the bracket- wire interface.

Articolo and Kusy (1999)[43] established the basis for binding and notching as the primary components of resistance to sliding. They studied the resistance to sliding as a function of angulation. They noted that the binding influence became greater as the wire-bracket angulation increased. With a 7 degree angulation, the binding made up 80% of the resistance to sliding; when the angle was increased up to 13 degree, binding produced 99% of the resistance to sliding,

Ryan and Walker (1997)[44] et al has reported contradictorily from Burstone's findings regarding ion implanted TMA wire. They demonstrated that, stainless steel produced the least frictional force during in vitro tooth movement, followed by ion-implanted nickel-titanium, ion-implanted beta titanium, untreated nickel-titanium, and finally, untreated beta-titanium. They concluded that there was in fact a statistically significant difference in the amount of movement seen with the ion-implanted wires when compared with their untreated counterparts.

Kusy RP et al (1997)[45] stated that. that the portion of applied force lost due to resistance to sliding can range from 12% to 60%.

Katherine Kula et al (1998)[46] Implantation of 0.019 ´ 0.025-inch TMA wire with two energies of nitrogen ion does not significantly enhance space closure compared with unimplanted TMA wire when unimplanted stainless steel brackets are used. However, the rate of closing on TMA wire during this study was similar to the reported rate of sliding closure on steel wire.

In the present study, brackets were not reused .This was in concurrence with the findings of **Kapur et al (1999)**[47] who reported that there was a distinct trend for the mean frictional force to be higher with the repeated use of the brackets.

Braun et al (1999) [9] reported that most frictional resistance studies have been conducted in a steady state condition that does not simulate the dynamics of the oral environment. Normal oral functions as chewing, swallowing, speaking, etc result in periodic, repetitive, minute relative motion at the bracket/arch wire interfaces several thousand times each day. Tests revealed that frictional resistance was effectively reduced to zero each time minute relative movements occurred at the bracket/arch wire interfaces. Factors such as the degree of dental tipping, relative arch wire/slot clearances, and method of tying, did not have a measurable effect on frictional resistance in the simulated dynamics of the oral environment

Michelberger (2000)[48] Ion-implanted beta-titanium wires generally had significantly larger coefficients of friction than stainless steel wires. The increased friction of the titanium and ion-implanted beta-titanium alloys is also reflected in the severity of their wear patterns. An inverse relationship between friction and archwire surface dimension was generally found for ion-implanted beta-titanium wires. Round stainless steel wires demonstrated lower coefficients of kinetic friction than the flat stainless steel wire surfaces.

Brantley et al (2001)[8] The clinical implication of friction was the slower rates of tooth movement observed during canine retraction and space consolidation with beta titanium wires than with stainless steel and Cobalt-Chromium wires. In order to reduce friction and improve esthetic characteristics, various coating methods have been tried over beta titanium archwires, such as ion implantation with diamond-like carbon and nitriding, which have shown limited success.

Brantley (2001)[8] SEM examination of beta-titanium orthodontic wires showed rough surfaces. This surface roughness, along with localized sites of cold welding or adherence by the wire to the bracket slots, could contribute to the increased archwire-bracket sliding friction seen with titanium-based archwires

Hussman (2002)[49] evaluated the in vitro frictional behavior of eight coated wires of different dimensions in archwire-guided canine retraction in the upper jaw. For this purpose five superelastic nickel titanium alloy wires, two beta-titanium wires, and one steel wire were selected. The coatings were made of Teflon or polyethylene, and by ion implantation. Three uncoated archwires were used for comparison purposes. The force losses due to friction were measured using the Orthodontic Measurement and Simulation System (OMSS).

The results indicated that all coatings can reduce frictional losses compared with an uncoated reference wire by the same manufacturer. Measured frictional losses ranged from 48.3-6.1%, with the Teflon coatings reducing the frictional losses to less than 10% in some cases. All coatings can reduce frictional losses compared with an uncoated reference wire by the same manufacturer. Measured frictional losses ranged from 48.3-6.1%, with the Teflon coatings reducing the frictional losses to less than 10% in some cases.

Jones et al (2002)[72] have reported contradictorily to the report of **Kapur** et al [47] recycling of brackets. They stated that, the changes in slot dimensions secondary to reconditioning did not result in a statistically significant difference in mean static frictional resistance when compared to new brackets. Although the brackets were altered physically by the reconditioning process, their performance during simulated sliding mechanics was not adversely affected. This implies that reconditioning may not result in clinically significant effects.

Darryl V Smith et al (2003)[77] studied the frictional resistance of various bracket archwire combinations. It was concluded that 1) ceramic brackets with and without metal slot had the greatest friction followed by metallic brackets, active self-ligating brackets, variable self-ligating brackets, and passive self-ligating brackets. 2) Stainless steel and braided stainless steel archwires measured greater friction than nickel- titanium. 3) smaller dimension wires had less friction than larger wires, and round wires had less friction than rectangular wires. In addition, consideration of specific bracket - archwire coupling appear to reduce the frictional resistance with sliding.

Cash et al (2004)[50] reported that honeydew-colored and ion-implanted TMA might allow space closure with minimal development of frictional forces.

Curtis (2004)[50] demonstrated that static and kinetic friction were statistically significant for all archwire types. Ion implantation and standard TMA archwires were found to have no significant advantage over stainless steel. Archwire alloys may be ranked as follows: SS produced the lowest friction followed by honeydew coloured TMA, and Timolium with aqua, purple and violet producing frictional resistance as high as standard TMA

Nishio et al (2004)[71] The beta-titanium wire showed the highest statistically significant frictional force value, followed by the nickel-titanium and the stainless steel archwires, in decreasing order. The frictional force values were directly proportional to the angulation increase between the bracket and the wire.

Simona tecco et al (2005)[78] performed an invitro study using a specially designed apparatus that included 10 aligned brackets to compare the frictional resistance generated by conventional stainless steel brackets, self-ligating Damon SL II brackets and Time Plus brackets coupled with stainless steel, nickel-titanium and beta-titanium archwires. All brackets had a 0.022-inch slot, and five different sizes of orthodontic wire alloys used. Each bracket-archwire combination was tested 10 times, and each test was performed with a new bracket-wire sample. Results showed -Time Plus self-ligating brackets generated significantly lower friction than both the Damon SL II self-ligating brackets and Victory brackets. However, the analysis ofthe various bracket-archwire combinations showed that Damon SL II brackets generated significantly lower friction than the other brackets when tested with round wires and significantly higher friction than Time Plus when tested with rectangular archwires. Beta-titanium archwires generated higher frictional resistances than the other archwires. All brackets showed higher frictional forces as the wire size increased. Also these findings suggest that the use of an in vitro testing model that includes 10 brackets can give additional interesting information about the frictional force of the various bracket-archwires combinations to the clinician and the research worker.

Astrid Verstrynge (2006)[51] Because of rough surfaces, TMA wire alloys are most likely to have surface alterations during clinical use. A recent in-vivo study on the surface characterization of retrieved nickel-titanium orthodontic archwires describes increased biofilm formation, surface delamination, and pitting corrosion. These alterations might profoundly modify the reactivity of the wire surfaces with undetermined effects on the corrosion resistance, nickel dissolution, and frictional resistance of the archwires.

Katz et al (2006)[52] has evaluated the static frictional property of orthodontic wires coated with tungsten disulphide an inorganic fullerene similar to molybdenum disulphide. The results showed that there was a substantial reduction in the friction resistance to sliding at different tilt angles, both in dry and wet modes. At an angle of 0 degrees the reduction of friction was only 17%. As the angle grew to 5 degrees, the reduction rate grew to 46% and the 10 degrees angle showed a 54% reduction of friction compared to the non-coated wire

The significant differences in the frictional values as a result of variation in the tilt angle may be attributed to the hypothesis proposed by **Rapoport** et al [53, 54]

At the first stage when there is no angle between the slot and wire, the inorganic fullerene particles act as spacers and reduce the number of asperities that come in contact, resulting in a lower coefficient of friction. As the angle grows the load at the edges of the slot increases causing the higher friction at the uncoated wire. It is probably at this point on the coated wire that the release of particles from the coating into the tribological interface and their exfoliation occurs, resulting in the formation of a solid lubricant film on the sliding wire.

The higher load at this point brings the asperities of the mating surfaces in straight contact causing the fluid (saliva in the mouth) to be squeezed out of the gap between the wire and slot, relying on the excellent tribological behavior of the solid lubricant film to allow the sliding of the archwire. When the two materials are SS, as is the case with the uncoated wire, the friction coefficient is high. The presence of the fullerene coating at the interface under high loads, leads to a very facile sliding between these sheets thereby reducing the coefficient of friction.Due to the tipping and uprighting type of tooth movement that is encountered during orthodontic treatment, this type of lubrication is most desirable.

Redlich et al(2008)[55] Reported that the wires coated with inorganic fullerene like nanoparticles like tungsten disulfide, might offer a novel opportunity to substantially reduce friction during tooth movement. A few tests undertaken to evaluate the toxicity of the fullerene-like nanoparticles have provided indications that they might be biocompatible. It was also suggested that Tungsten disulfide and molybdenum disulfide particles.

Low friction and wear is associated with the penetration of solid lubricant WS2 nanoparticles into the interface between rubbed surfaces. As the load between the bodies increases, the nanoparticles gradually deform and exfoliate, leaving particles of the sandwiched material to coat the asperities at the interface. The weak forces, between the thin sheets of the exfoliated particles, allow a low shear force sliding motion between the two contacting bodies.

Doshi et al (2011)[56] NiTi wires, although smoother than colored TMA, showed higher friction values. The higher free titanium content in NiTi wires could explain the higher frictional values. Colored TMA is a good alternative to SS wires in sliding mechanics during space closure, since it has good formability, resiliency, and lower frictional resistance.

Mugurama et al (2011)[57] Used a diamond like carbon coating (DLC) on two types of wires (nickel-titanium and stainless steel). Three types of brackets, a conventional stainless steel bracket and two self- ligating brackets, were used for measuring static friction.

They reported that the DLC-coated wires showed significantly less frictional force than the as-received wires, except for some wire/bracket combinations. Thin DLC layers were observed on the wire surfaces by SEM. As-received and DLC-coated wires had similar surface morphologies, and the DLC-coating process did not affect the surface roughness. The hardness of the surface layer of the DLC-coated wires was much higher than for the as-received wires.

The present study to evaluate the static frictional properties was done in the dry state. This was based on the report by Al –Mansouri et al

Al-Mansouri et al (2011)[58] evaluated the effects of lubrication on static frictional force of orthodontic brackets. Their study aimed to compare the effects of human saliva and an artificial saliva , with the dry state for the static frictional resistance testing. Artificial saliva is not an ideal alternative to human saliva for friction testing in the laboratory. They concluded that when human saliva is not available, it may be preferable to test orthodontic frictional resistance in the dry state of orthodontic brackets and wires.

Al-Mansouri's evaluation in the dry state study however contradicts the report by **Downing et al**[40] - The effect of artificial saliva on the static and kinetic frictional forces of stainless steel and polycrystalline ceramic brackets in combination with 0.018-inch round and 0.019 x 0.025-inch Edgewise archwire sizes and stainless steel, nickel-titanium and beta-titanium archwire materials, under a constant ligature force were investigated. In all cases, artificial saliva had the effect of increasing the frictional force when compared with the dry state.

Husain et al (2011)[70] reported that frictional force was seen to be inversely proportional to bracket width, frictional force was inversely proportional to bracket width, and in the wet condition were greater than in the dry condition for all archwire to bracket combinations. Hence greater applied force is needed to move a tooth with a bracket archwire combination demonstrating high magnitudes of friction compared with one with a low frictional value.

Arun et al (2011)[75] Reported that polymeric surface coatings and introduction of angulations into elastomeric ligatures reduce the friction during sliding; however, the diameter of the ligature made no difference to sliding friction. The findings of Arun et al agree with the Berger et al[74] report on the effect of method of ligation on amount of friction generated.

Krishnan et al (2012)[58] attempted a physical vapour deposition coating of TMA wires with WC/C and TiAlN. They reported that such coated wires can be recommended for even sliding mechanics due to reduced frictional properties, better surface characteristics, and low load deflection rate compared with TiAlN coated and uncoated archwires

Liu et al (2012)[73] reported that orthodontic treatment results in significant increase in surface roughness and coefficient of friction for brackets. However, there was no significant difference for new or retrieved brackets. The retrieval analysis results highlight the necessity of reevaluating the properties and clinical behavior of brackets during treatment to make appropriate treatment decisions.

Farronata and Maijer (2012)[59] reported the efficacy of teflon coated stainless steel and Nickel titanium wire. They concluded that for all bracket–archwire combinations, Teflon-coated archwires had lower friction than the corresponding uncoated archwires .The results showed that Teflon coating has the potential to reduce resistance to sliding of orthodontic archwires.

Materials & Methods

The present study involved the coating of rectangular **TMA** and **Stainless steel** (**SS**) archwires with Molybdenum Disulfide (MoS_2), which is an extensively used metal dichalcogenide solid lubricant .This has been done with the objective of reducing the static frictional properties of the archwires during sliding mechanics.

The mechanical testing was performed at the Biomedical Testing wing of the Sree Chitra Tirunal Institute for Medical Sciences and Technology, Thiruvananthapuram and Sree Mookambika Institute of Dental Sciences, Kulasekaram.

The analysis was intended to compare the static frictional properties of molybdenum disulfide coated stainless steel and TMA archwires and uncoated stainless steel and TMA archwires with stainless steel brackets.

Materials Used

Brackets

The brackets which were used for the study are .022 x .028” Stainless steel MBT prescription Maxillary right canine, 8^{o} tip, zero torque brackets (Ormco Corp, Glendora, Calif).

A total of 40 brackets were used for the study. (Fig 1)

Archwires

Four types of archwires were used for the study:

1. **Uncoated TMA archwire** (Ormco-Glendora, Calif)

- .019 x .025 inch straight length - (Fig. 3)
- 10nos

2. **Uncoated Stainless Steel archwire** (Ortho Technology, Tampa, USA)

- **.**019 x .025 inch straight length (Fig.2)
- 10 nos.

3. **Molybdenum Disulfide Coated Stainless steel archwire**

– .019 x .025 inch straight length (Fig 2)

- 10 nos.

4**. Molybdenum Disulfide coated TMA archwire**

- .019 x .025 inch straight length (Fig 3)

- 10 nos

Wire Coating Used

A **Molybdenum disulfide** (MoS_2) coating of 3(+/- 0.5) micron thickness was done on TMA and Stainless steel wires .The coating was done on 10 archwires each of stainless steel and TMA.

The process of coating involved 3 cycles of surface cleaning with the same alkaline surfactant, to ensure that the surface of the archwire was devoid of any organic impurity. The wires were then transferred to a fixture to optimally position it within the coating chamber (Fig 8).The holding fixture was used to ensure maximum coverage of the coating on the wire. The coating material was formulated in an aqueous base with an ethyl silicate binder.

The wires were coated by an automated, **ionized spray deposition** process in a coating chamber (Fig.8) to an average coating thickness of 3 +/- 0.5 micron. The speed and thickness of coating was controlled using a calibrated orifice. The time required for completion of the coating process for one batch of archwires was 3 hours. After coating the wires were dried and subject to a baking process at **$240^{o}C$**, for a period of 2 hours. This was done in order to ensure a proper dry adhesion. The wires were inspected for coverage and adhesion test done to ensure the required bond is achieved between the base archwire and MoS_2.

Ligature wire

All the archwires were ligated using standard .009” stainless steel ligature (304L Stainless steel) wire of 4 cm length each. It was wound fully by 10 turns and unwound by 2 turns (Fig 7) as advocated by **Hain** et al [66]

Testing Machine

The equipment used for testing was the **Instron 3345** (Instron Corp,Canton, Massachussets, USA) .(Fig 9) floor mounted unit. The load cell was calibrated between 0 and 100 N. The archwire was pulled through the bracket at a crosshead speed of 1 mm / minute and a 5 N force. The wire was pulled through a distance of 10 mm. Each bracket-archwire combination was tested 10 times. The peak load was measured in Newton (N) for each specimen, and readings plotted as a load-displacement curve

Isopropyl Alcohol

70 % isopropyl alcohol was used to clean the bracket surfaces and the surface of the uncoated archwire surface before fixing. (Fig 1)

Adhesive

An epoxy adhesive (Araldite Ciba-Geigy, plc, Stafford, UK) was used to bond the brackets. (Fig 1)

Perspex Sheet

Clear Perspex sheets of 150 mm x 30 mm x 3 mm were used. (Fig 4)

Marking Pen

An alcohol-based, waterproof glass marking pen (Faber-Castell) was used to draw the horizontal marking lines on the Perspex sheet (Fig.1)

Positioning Jig

The positioning jig was fabricated using .021 x .025” stainless steel wire as advocated by **Thomas et al**.[60] (Fig 5, 6)

Elastomeric modules

Grey coloured elastomeric modules (GAC-Dentsply,USA) were used to position the bracket in the jig while the adhesive hardened. (Fig 1)

<u>Constitution of Archwire Test Groups</u>.

In the present study, the archwires were categorized into **4 groups** to evaluate the static frictional values. **10 archwires** were taken per group; therefore testing was done for a total of 40 archwires. The length of each sample archwire was 15 cm.

1. **Group I (USS)**

   - Stainless Steel wire (Ortho Technology – Tampa, Florida, USA)

   - .019 x .025" straight length (10 no)

2. **Group 2 (UTMA)**

   - TMA wires (Ormco-Glendora, Calif)

   - .019 x .025" straight length- (10 no)

3. **Group 3 (CSS)**

   - MoS_2 coated SS wires

   -.019 x .025" straight length (10 no)

4. **Group 4 (CTMA)**

   - MoS_2 coated TMA wire

   -.019 x .025" straight length (10 no)

This wire dimension was selected as it is most commonly used during retraction in treatment with the preadjusted straightwire systems.

Methodology

For the study, 40 maxillary right canine brackets were cleaned using 70 % isopropyl alcohol to clear the bracket surfaces of any impurities. The uncoated wires were also cleaned using isopropyl alcohol.

As advocated by **Doshi et al**[56]**,** sheets of clear Perspex having dimensions of 150 x 30 x 3 mm were taken. Each sheet had a line marked in the midline parallel to the long axis of the sheet to serve as a guide to ensure a reproducible bond position. (Fig 4)

The positioning jig was fabricated according to the design described by **Thomas et al**[60] and **Sims et al**[61] using a .021 x .025 SS wire. The brackets were bonded onto the Perspex sheet using epoxy adhesive (Araldite, Ciba-Geigy, plc, Stafford, UK). The jig was held in position while the adhesive hardened. (Fig 5)

For each test, a new bracket and a 15 cm length of archwire was taken .The archwire was ligated to the bracket using 4cm lengths of .009” ligature wire. It was ligated by fully winding ten times and unwound by two turns as advocated by **Hain et al** [66] (Fig 7)

The bracket - archwire assembly was then mounted and positioned vertically in the Instron 3345 floor mounted machine. (Fig.9)

The archwire protruding from the bracket was carefully clamped to the upper jaws of the moveable crosshead, while the Perspex sheet was clamped to the lower arm. It was ensured that the wire was parallel to the line which was marked on the Perspex sheet.

The plumbline present on the testing machine helped to ensure that the bracket and archwire was parallel to the vertical pulling force of the testing machine. It was also ensured that there was no twisting of the wire during at any stage of the testing procedure.

All the tests were performed in the dry state at room temperature. The load cell was calibrated between 0 and 100 N. The archwire was pulled through the bracket at a crosshead speed of 1 mm / minute and a 5 N force. Each bracket-archwire combination was tested 10 times.

As advocated by **Kapur et al**[47], the brackets were not reused. Each time a new bracket and wire was used to eliminate the possibility of wear and notching.

Statistical Analysis

The data that was obtained by mechanical testing was analyzed using **SPSS version 16.0 (**SPSS-IBM Inc., Chicago, IL, USA) Student “t” test was used to find significant difference between the groups. One way ANOVA was used for statistical analysis. Post Hoc test, followed by Scheffe’s test which was used for multiple comparisons. $P < 0.05$ between groups was considered statistically significant.

Results

The present study involved the coating of rectangular **TMA** and **Stainless steel** (**SS**) archwires with **Molybdenum disulphide (MoS_2)** which is an extensively used metal dichalcogenide solid lubricant .This has been done with the objective of reducing the static frictional properties, and in an attempt to improve the properties of stainless steel wires.

The analysis was intended to compare the static frictional properties of molybdenum disulfide coated stainless steel and TMA archwires with uncoated stainless steel and TMA archwires. In the present study, the archwires were categorized into **4 groups** (10 specimens / Group) to evaluate the static frictional values:

1. **Group I (USS) -**Stainless Steel wire - .019 x .025 inch
   (Ortho Technology – Tampa, Florida, USA)
2. **Group 2 (UTMA)** - TMA wires - .019 x .025 inch straight length
   (Ormco -Glendora, Calif)
3. **Group 3 (CSS)** - MoS2 coated SS wires - .019 x .025 inch straight length
4. **Group 4 (CTMA)** - MoS2 coated TMA wire -.019 x .025 inch straight length

The brackets that were used are .022 x .028” MBT prescription maxillary right canine brackets with zero torque.

The static frictional values for all specimens were recorded for each group, using the Instron 3345 machine.

The data was analyzed using SPSS (16.0) version. Student “t” test was used to find significant difference between the groups. One way ANOVA was used for statistical analysis. Post Hoc test, followed by Scheffe’s test which was used for multiple comparisons. $P < 0.05$ between groups was considered statistically significant.

The values obtained in Newton (N) were:

Group I - 1.51 +/- 0.28 N

Group II - 2.97 +/- 0.13N

Group III - 1.17 +/- 0.10 N

Group IV - 1.74 +/- 0.34 N

(Indicated in **Table -1**)

Graphs 1- 4, indicate the peak load values obtained from the load-displacement graph for each specimen in Groups I- IV.

Table-3 compares Group -I with other groups .P <0.05 was considered significant. The comparison shows that there was a statistically significant difference when Group I was compared with Group II and III. There was however no statistically significant difference when compared with Group IV. This is represented in Graph-6.

Table-4 compares Group II with Group I, III and IV. P< 0.05 was considered statistically significant. The comparison indicated that there was a statistically significant difference for group II with all other groups. Represented in Graph7. **Table-5** compares III with Groups I, II, IV. Group III showed a statistically significant difference when compared to all other groups. This is represented in **Graph-8**.

A comparison of **Group IV,** with other groups, as shown in Table-6. indicates a statistically significant difference in comparison to Group II and III. There was however no statistically significant difference with group I as indicated in **Graph-9**.

Multiple comparison was done using Scheffe’s test as indicated in **Table-7**.P value <0.05 was considered statistically significant. Group I showed a statistically significant difference

In comparison to Group II and III. Group II showed a statistically significant difference in comparison to Group III and IV. Group III showed a statistically significant difference when compared to Group IV.

The multiple comparison graph is illustrated in **Graph-10**.

Tables

Tables

Table-1: Load at max values of different materials

Sample Number	Load at Max of USS	Load at Max of UTMA	Load at Max of CSS	Load at Max of CTMA
1	1.74	2.98	1.23	1.84
2	1.97	2.86	1.06	1.90
3	1.55	2.79	1.18	1.89
4	1.73	3.02	1.06	1.92
5	1.31	3.18	1.29	1.98
6	1.67	2.95	1.31	1.85
7	1.12	3.10	1.09	1.00
8	1.31	2.85	1.17	1.98
9	1.15	2.92	1.21	1.15
10	1.55	3.10	1.10	1.85
(MEAN±SD)	**1.51±0.28**	**2.97±0.13**	**1.17±0.10**	**1.74±0.34**

Table-2: Mean values of different materials

Groups	Composition of materials	Load at Max (MEAN±SD)
Group-I	Uncoated Stainless Steel (USS)	1.51±0.28
Group-II	Uncoated TMA (UTMA)	2.97±0.13
Group-III	Coated Stainless Steel (CSS)	1.17±0.10
Group-IV	Coated TMA (CTMA)	1.74±0.34

Table-3: Comparison of mean Load at Max values of USS with other groups

Groups	Composition of materials	Load at Max (MEAN±SD)
Group-I	Uncoated Stainless Steel (USS)	1.51±0.28
Group-II	Uncoated TMA (UTMA)	2.97±0.13*
Group-III	Coated Stainless Steel (CSS)	1.17±0.10*
Group-IV	Coated TMA (CTMA)	1.74±0.34

Table-4: Comparison of mean Load at Max values of UTMA with other groups

Groups	Composition of materials	Load at Max (MEAN±SD)
Group-II	Uncoated TMA (UTMA)	2.97±0.13
Group-I	Uncoated Stainless Steel (USS)	1.51±0.28*
Group-III	Coated Stainless Steel (CSS)	1.17±0.10*
Group-IV	Coated TMA (CTMA)	1.74±0.34*

Table-5: Comparison of mean Load at Max values of CSS with other groups

Groups	Composition of materials	Load at Max (MEAN±SD)
Group-III	Coated Stainless Steel (CSS)	1.17±0.10
Group-I	Uncoated Stainless Steel (USS)	1.51±0.28*
Group-II	Uncoated TMA (UTMA)	2.97±0.13*
Group-IV	Coated TMA (CTMA)	1.74±0.34*

Table-6: Comparison of mean Load at Max values of CTMA with other groups

Groups	Composition of materials	Load at Max (MEAN±SD)
Group-IV	Coated TMA (CTMA)	1.74±0.34
Group-I	Uncoated Stainless Steel (USS)	1.51±0.28
Group-II	Uncoated TMA (UTMA)	2.97±0.13*
Group-III	Coated Stainless Steel (CSS)	1.17±0.10*

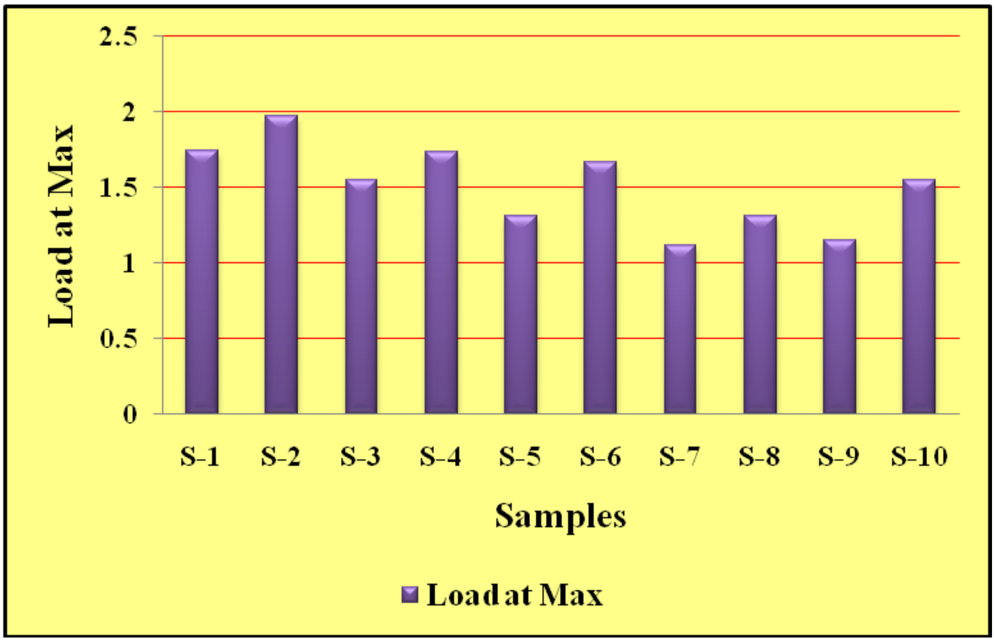
Table-7: Multiple comparison of mean Load at Max values of different groups

Groups	Composition of materials	Load at Max (MEAN±SD)
Group-I	Uncoated Stainless Steel (USS)	1.51±0.28
Group-II	Uncoated TMA (UTMA)	2.97±0.13*
Group-III	Coated Stainless Steel (CSS)	1.17±0.10*,#
Group-IV	Coated TMA (CTMA)	1.74±0.34#,$

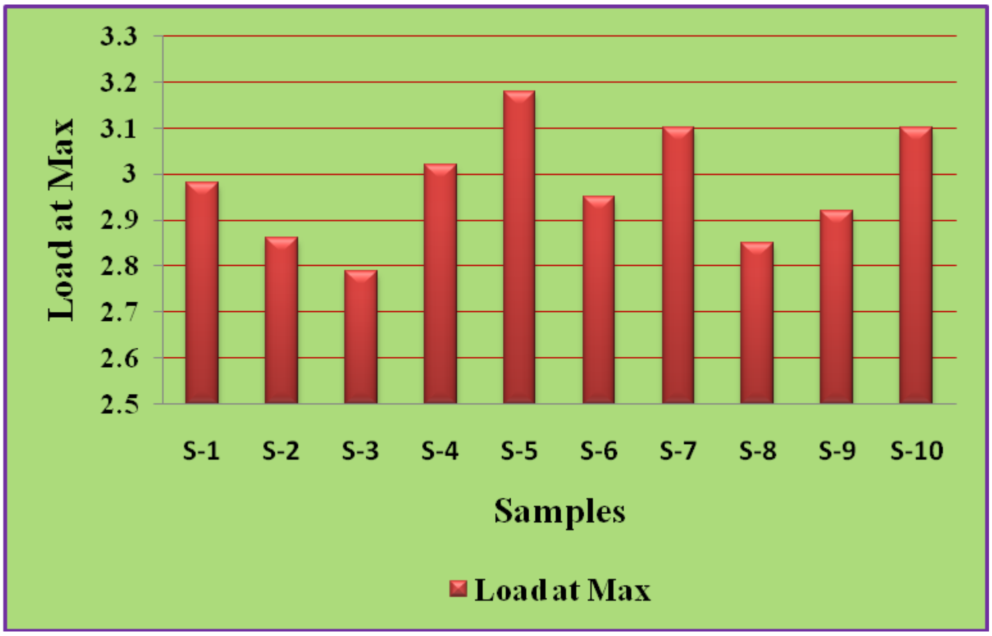
Graphs

Graphs

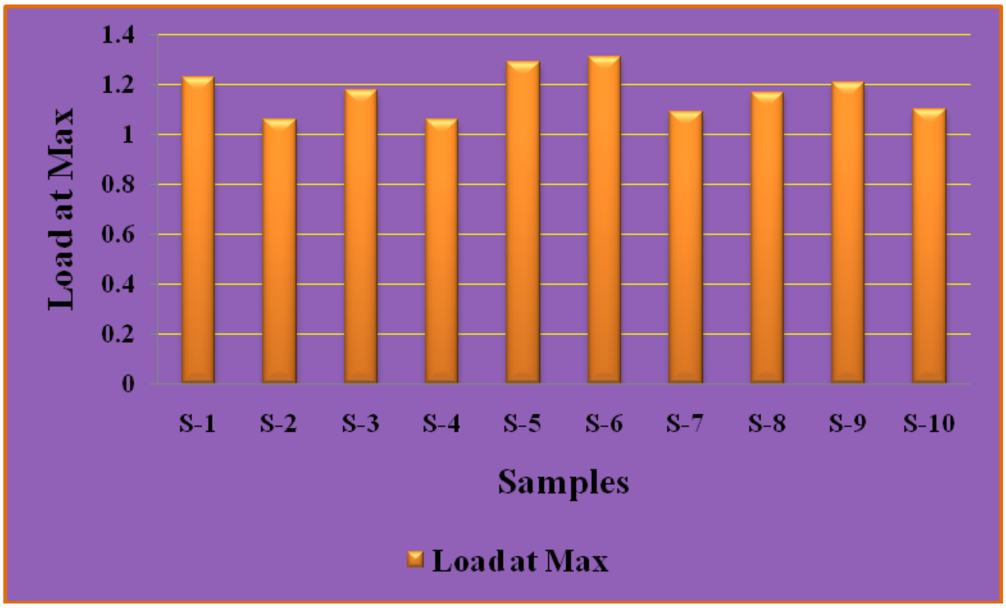
Graph-1: Samples showing Load at Max of USS



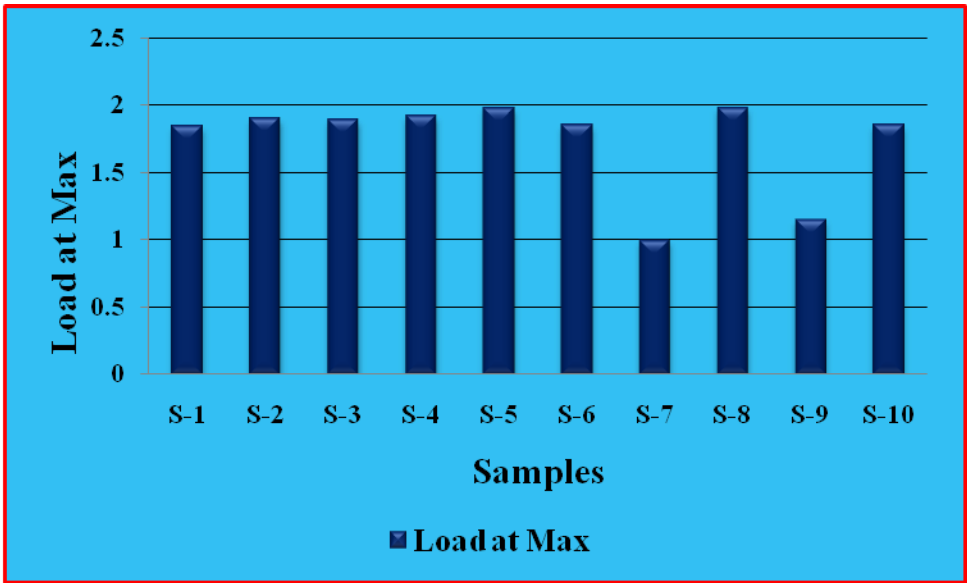
Graph-2: Samples showing Load at Max of UTMA



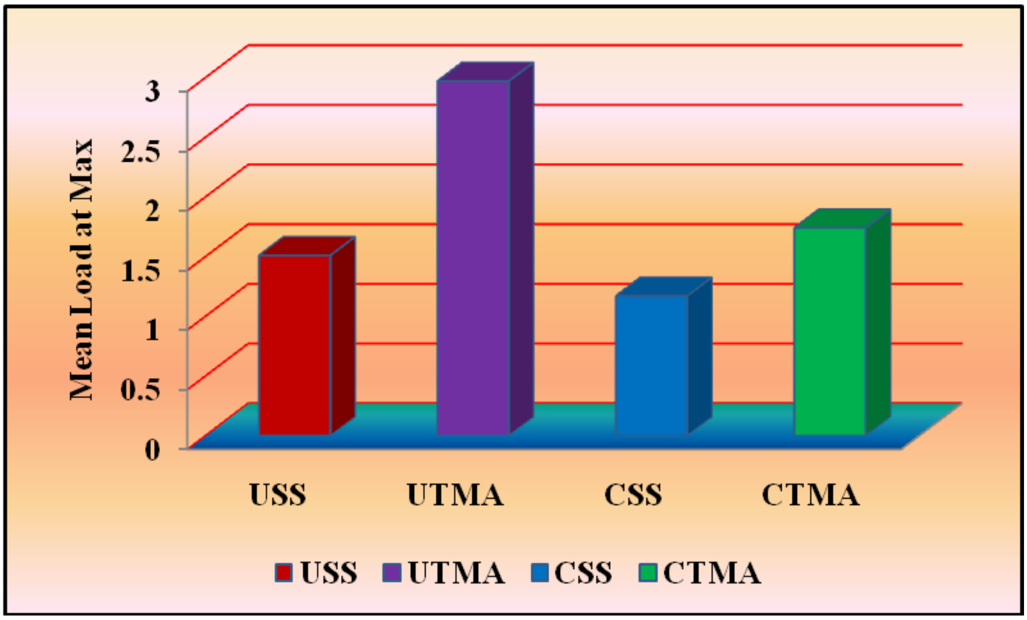
Graph-3: Samples showing Load at Max of CSS



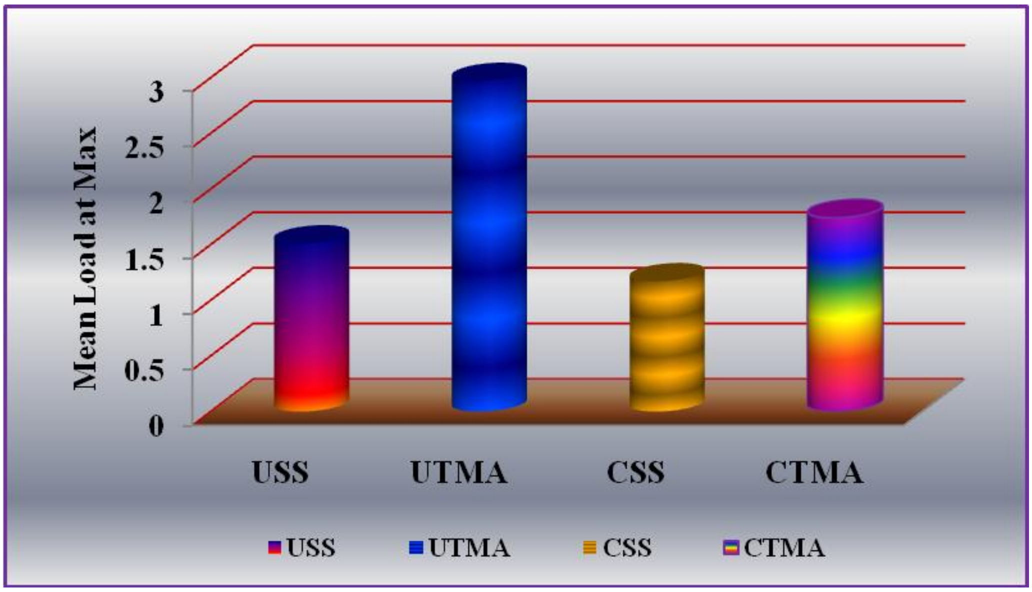
Graph-4: Samples Showing Load at Max of CTMA



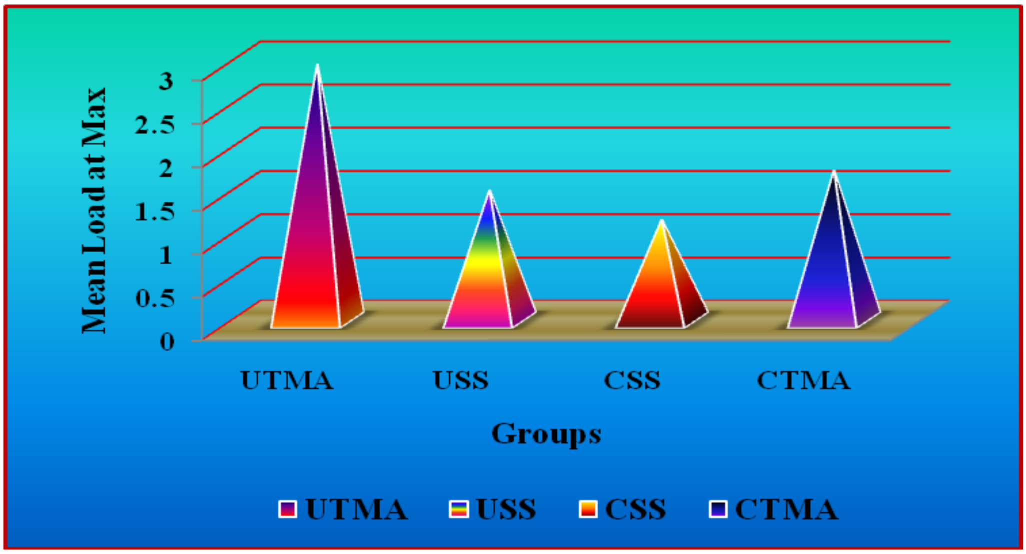
Graph-5: Mean values of different materials



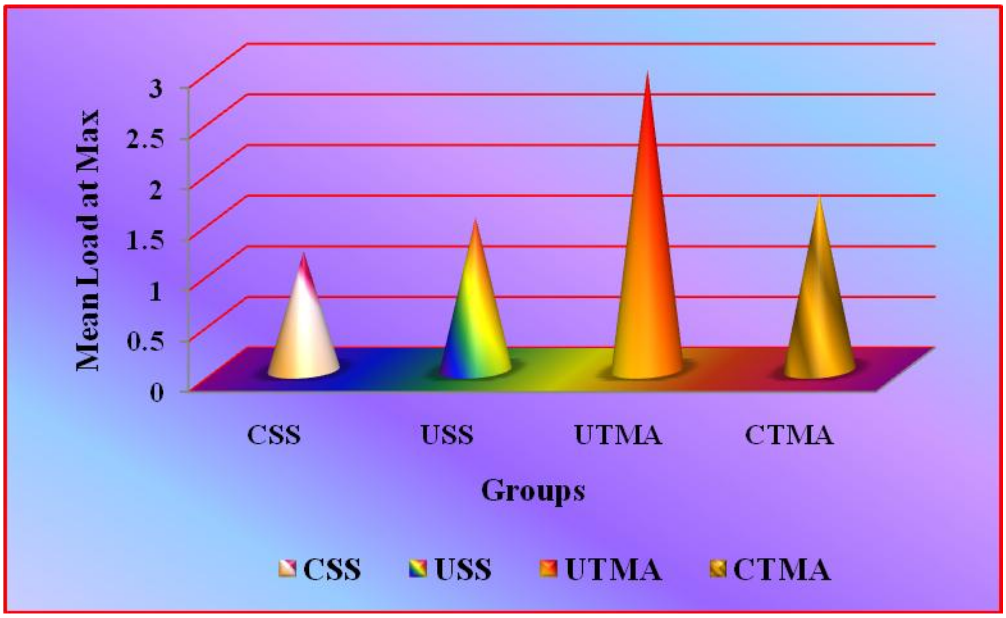
Graph-6: Comparison of mean Load at Max values of USS with other groups



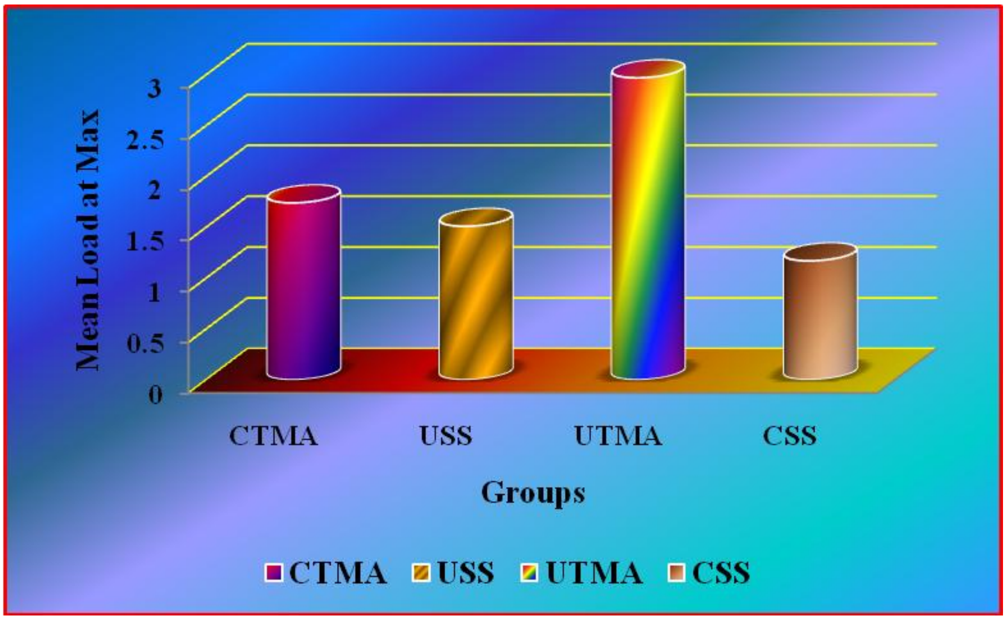
Graph-7: Comparison of mean Load at Max values of UTMA with other groups



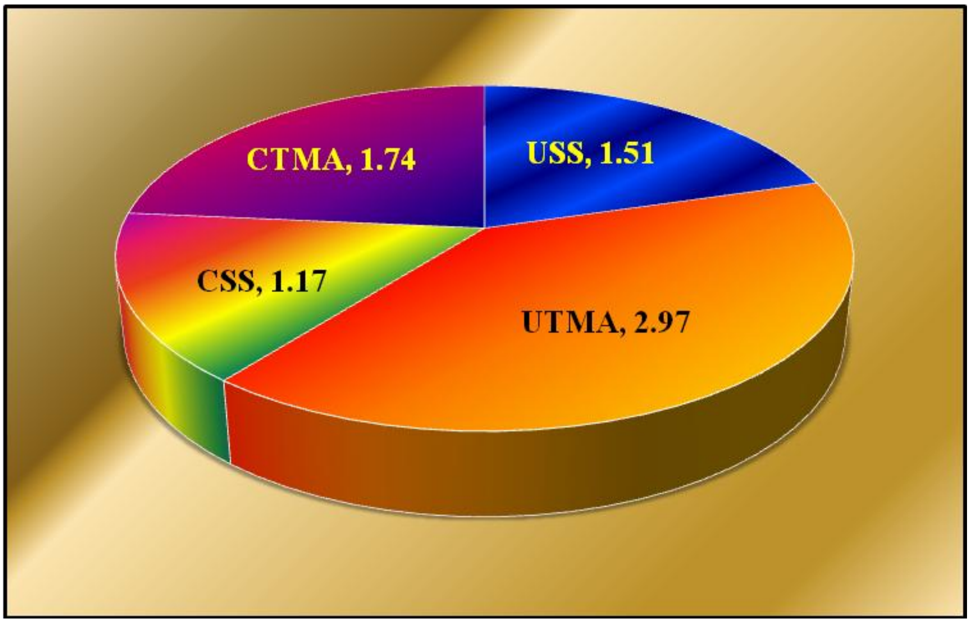
Graph-8: Comparison of mean Load at Max values of CSS with other groups



Graph-9: Comparison of mean Load at Max values of CTMA with other groups



Graph-10: Multiple comparison of mean Load at Max values of different groups



Discussion

An issue which is commonly encountered during treatment with the pre-adjusted edgewise appliance is the friction that arises between the bracket and the archwire during space closure employing sliding mechanics. This relates to a reduction in the rate of tooth movement and an increased toll on the anchorage requirements. Owing to this critical role which friction plays during sliding mechanics, it is most advisable to use materials and techniques which would generate the least amount of friction, resulting in a more efficient orthodontic treatment outcome.

In the clinical environment, the tooth movement begins in the alveolar socket when the retraction force exceeds the resistance offered by the periodontium and the frictional forces in the bracket.[62]

Initially, upon appliance activation the delivered force is sufficient to overcome the frictional forces and tooth movement takes place. This movement continues until the resistance of the deformed periodontal support structure builds to a value which, when added to the kinetic force, offsets the delivered force.[62]

Optimal force magnitude during orthodontic treatment will result in proper tissue response and rapid tooth movement. Also optimum force levels stimulate cellular activity without completely occluding blood vessels in the periodontal ligament. Higher forces are likely to create a hyalinized avascular area that must be revascularized before the next phase.

During mechanotherapy involving movement of the wire along the brackets, friction at the bracket-archwire interface might prevent attaining optimal force levels in the supporting tissues.[63]

Frictional forces in continuous arch mechanics must be overcome for a favorable periodontal response intended for tooth movement. It has been proposed that about 12- 60% of the force applied to slide a tooth is used to overcome friction.[64] However, light forces and lower frictional values are more favorable to initiate and maintain tooth movement because they can result in a less painful treatment experience for the patient and also help to maintain the position of anchorage teeth. [6,7,10]

In the present study, TMA and stainless steel archwires were coated with **Molybdenum Disulfide (MoS_2)**,which is a commonly used metal dichalcogenide solid lubricant. This dry lubricant coating has been used extensively for aerospace applications, fasteners, as an industrial solid lubricant, military applications and in the automotive industry. Molybdenum Disulfide is a relatively inexpensive, easily available, non-toxic[65] coating. Molybdenum disulfide is often a component of blends and composites where low friction is sought. A variety of oils and greases are used, because they retain their lubricity even in cases of almost complete oil loss, thus finding a use in critical applications such as aircraft engines. When added to plastics, MoS_2 forms a composite with improved strength as well as reduced friction.

Polymers that have been filled with MoS_2 include some types of nylon, and Teflon.

MoS_2[65] has a crystalline structure in which a Molybdenum (Mo) layer is sandwiched between two layers of sulphur (S) with molybdenum in a trigonal biprism coordination. There are strong covalent forces which exist between Mo & S atoms within a lamella, whereas adjacent lamellae are linked through relatively weak Van Der Waal forces.[65] Owing to these weak interlamellar forces, a shear occurs when the direction of sliding is parallel to the planes of the material. This graphite like property and structure might be responsible for the lubricant properties of this coating.

Sastri et al[67] have stated the benefits of application of molybdenum disulfide coatings on medical equipment such as tubings, catheters, guidewires etc which are used for minimally invasive procedures. The lubricious surface prevents the adhesion of fluids or materials to the device or component and enables a smooth passage through the body.

The molybdenum disulfide coating which was selected for the present study bears an advantage owing to its easy availability and economy of coating. The greatest advantage however, lies in the fact that this is a relatively low temperature coating, with a coating temperature of approximately **240^{o}C**, which was far below the melting range of TMA and stainless steel wires.[58]

Krishnan et al [68] have stressed the importance of keeping coating temperatures at relatively low levels to maintain the mechanical properties of archwires during coating .The coating temperatures of approximately 250^{0}C during the heating process was not crossing the melting range of the beta titanium alloy and was not found to affect the mechanical properties of the archwires.

The present study was undertaken in the dry state, in accordance with the report by **Al-Mansouri et al**[57] who reported that artificial saliva is not an ideal alternative to human saliva for friction testing in the laboratory They concluded that when human saliva is not available, it may be preferable to test orthodontic frictional resistance in the dry state of orthodontic brackets and wires.

Downing et al [40] contradicted these findings. They reported that in all cases, artificial saliva had the effect of increasing the frictional force when compared with the dry state.

As advocated by **Kapur et al** [47], the brackets were not reused. Each time a new bracket and wire was used to eliminate the possibility of wear and notching.

The .022x.028” stainless steel MBT prescription brackets were selected for the study because sliding mechanics with the preadjusted appliance performs best in the .022” form. The larger slot allows more freedom of movement in the early stages, and the rectangular .019 x .025” working wires perform well in the later stages. The .019 x .025 archwires were selected for the study because this is the working wire for the particular slot dimension.[69]

An in-vitro evaluation of static frictional properties with the Instron3345 machine was done, owing to the difficulty in measuring and quantifying these values in the in-vivo condition.

In this study we compared the frictional resistance of Molybdenum Disulfide coated stainless steel and TMA wire and uncoated stainless steel and TMA wire within a .022x .028 ” MBT prescription stainless steel bracket.

The archwires were categorized into 4 groups namely **Group I**(USS), **Group II** (UTMA), **Group III** (CSS) , **Group IV**(CTMA) .to evaluate the static frictional values. 10 archwires were taken per group; therefore testing was done for a total of 40 archwires. The length of each sample archwire was 10 cm. The mechanical testing was performed and the peak load recorded. The values were obtained in Newton (N) as indicated in Table -1.

The statistical analysis indicated that when uncoated stainless steel (USS) was compared with uncoated TMA and coated stainless steel, there was a statistically significant difference between the groups. Uncoated stainless steel archwire had a statistically significant reduction in static frictional value as indicated in Graph-6.

When uncoated TMA archwire was compared to uncoated stainless steel archwire, coated stainless steel archwire and coated TMA archwire, it showed a statistically significant difference. Uncoated TMA showed the highest mean value for peak load, among all groups as indicated in Graph-7 .This finding was in concurrence with studies by various authors like **RP Kusy**[35], **Prosoki et al** and **Garner et al**[36] who stated TMA wires as having the highest frictional values. The rationale for the increased friction with beta titanium wires may be adherence of the wire material to the material of the bracket slot.

A comparison of coated stainless steel (CSS) wires with the other groups indicated that this group had a statistically significant difference in comparison with all other groups, as represented in Graph -8. Coated stainless steel wires had the lowest mean values as indicated in Table 2.

The multiple comparison done using Scheffe’s test indicated that there was no statistically significant difference between uncoated stainless steel wire and coated TMA.

There was a statistically difference for coated stainless steel wire in comparison to all other groups. The coated stainless steel archwires showed the lowest value for static friction, as represented in Graph-10.

It may be stated based on the analysis in the study that MoS_2 coated archwires showed significantly lower values for friction when compared to its uncoated counterparts. The mean values for coated TMA wires showed no statistically significant difference from an uncoated stainless steel archwire. This indicates that MoS_2 coated TMA archwires may be used during the space closure stage of orthodontic mechanics, when sliding mechanics is employed.

The efficacy of coating TMA archwires has been reported in the study done by **Krishnan et al**[58]**,** who used a WC/C coating for enhancing surface morphology and reducing frictional properties. They have stated that WC/C coated TMA wires may be employed effectively for sliding mechanics.

The results of the present study also agree with the findings of **Katz, Redlich et al**[55] who attempted coating of orthodontic wires with an inorganic fullerene-like coating, similar to MoS_2.They reported a significant reduction in static frictional values.

The reduction in friction of the coated wires may be explained on the rationale provided by **Rapoport et al**[54]. Initially, when there is no angle between the slot and wire, there would be a reduction in friction when the MoS_2 particles act as spacers and reduce the number of asperities that come in contact. When the angle changes, the load at the edges of the slot increases, there would resultantly be a higher friction at the uncoated wire.

In the case of the coated wire, it is under this circumstance that the release of inorganic fullerene-like particles occurs. There is an exfoliation of the coating particles into the interface, which results in the formation of a solid lubricant film on the sliding wire. The higher load at this point brings the asperities of the contacting planes in straight contact causing the fluid when present (saliva in the mouth) to be squeezed out of the gap between the wire and slot, relying on the properties of the solid lubricant film to allow the sliding of the archwire. When the two materials are SS and TMA, as is the case with the uncoated wire, the friction coefficients are high. The presence of the solid lubricant particles at the interface under relatively high loads, leads to a sliding between these sheets resulting in a lower friction..

However, the use of any material in vitro and in vivo requires that they be biocompatible. The cytotoxic behavior of MoS_2 particles on cells was examined by **Wu et al** [65]. The results of their study showed that the MoS_2 nanoparticles were relatively nontoxic and biocompatible**.** It was found that the MoS_2 particles were nontoxic to the cells at the tested concentrations. They concluded that MoS_2 particles seem to have a relatively good biocompatibility with the tested human cells.

Limitations of this study would be an interpretation of this in-vitro study to an in vivo situation. As might be expected with any testing situation, it would not be possible to exactly simulate the conditions one might encounter in the oral environment. Additionally, evaluations of the effect of this coating on the solderability and weldability of the wires have not been done as it was beyond the scope of the present study. Further, extensive biocompatibility tests will need to be performed before such coatings may be attempted.

In the present study we found that the coated stainless steel wires offered the lowest frictional resistance. The highest frictional resistance was offered by the uncoated TMA wire. There was no statistically significant difference in the frictional resistance offered by uncoated stainless steel wire and coated TMA wire. This study implies that coated TMA archwires may be used during the space closure stage of orthodontic mechanics, when sliding mechanics is employed.

The present study indicates the efficacy of archwire coating in reducing the static frictional values. This holds the future prospect of commercially introducing such archwires for clinical applications.

Extensive clinical trials over long period are needed to evaluate the in-vivo effects of the frictional characteristics of such coated archwires.

Summary & Conclusion

In the present study we have compared the frictional resistance of Molybdenum Disulfide coated stainless steel and TMA wire and uncoated stainless steel and TMA wires in a .022x .028” stainless steel MBT prescription bracket using an Instron 3345 universal testing machine.

This study indicated a statistically significant difference when uncoated stainless steel wire was compared with uncoated TMA and coated stainless steel wires. Also there was no statistically significant difference when compared with coated TMA wire. Comparison of uncoated TMA wire with uncoated stainless steel, coated stainless steel and coated TMA wires indicated that there was a statistically significant difference for uncoated TMA wire with all other groups. Coated stainless steel wires showed a statistically significant difference when compared to all other groups. A comparison of Coated TMA wires with other groups, indicated a statistically significant difference in comparison to uncoated TMA and coated stainless steel wires. There was however no statistically significant difference when compared with uncoated stainless steel wire.

Multiple comparison done using Scheffe’s test indicated that uncoated stainless steel wires showed a statistically significant difference in comparison to uncoated TMA and coated stainless steel wires. Uncoated TMA wires showed a statistically significant difference in comparison to coated stainless steel and TMA wires. Coated stainless steel wires showed a statistically significant difference when compared to coated TMA wires.

Further studies are required for the evaluation of archwire properties like solderability, weldability of Molybdenum Disulfide coated Stainless steel and TMA wires.

Based on statistical evaluation of the data obtained, the following **conclusions** were drawn:

a) Among the 4 groups compared, the coated stainless steel wires offered the lowest frictional resistance.
b) The highest frictional resistance was offered by the uncoated TMA wire.
c) There was no statistically significant difference in the frictional resistance offered by uncoated stainless steel wire and coated TMA wire.
d) Molybdenum Disulfide coated TMA archwires may be used during the space closure stage of orthodontic mechanics, when sliding mechanics is employed.

e) The frictional resistance offered by the wires were in the following order :

Molybdenum Disulfide coated stainless steel archwires offered the lowest amount of frictional resistance followed by uncoated stainless steel archwire .The frictional resistance offered by the Molybdenum Disulfide Coated TMA archwires were higher than uncoated stainless steel archwires. Uncoated TMA archwires had the highest value of frictional resistance.

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